

SDSS-III/APOGEE: Detailed Abundances of Galactic Star Clusters

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Abstract The Sloan Digital Sky Survey III/Apache Point Observatory Galactic Evolution Experiment (SDSS-III/APOGEE) is a large-scale spectroscopic survey of Galactic stars and star clusters. The SDSS-III/APOGEE survey is designed to produce high- S/N , $R = 27,500\text{--}31,000$ spectra that cover a wavelength range of 1.51 to 1.68 microns. By utilizing APOGEE's excellent kinematics (error ≤ 0.5 km s $^{-1}$) and abundances (errors ≤ 0.1 dex), we will be able to study star cluster kinematics and chemical properties in detail. Over the course of the 3-year survey beginning in 2011, APOGEE will target 25–30 key open and globular clusters. In addition, the large area coverage of the SDSS focal plane will also allow us to target stars in 100–200 additional star clusters during the main survey observations. We present the strength of APOGEE for both open and globular star cluster studies and the methods of identifying probable clusters members utilizing 2MASS and IRAC/WISE data.

1 Introduction

Star clusters represent a key tracer for the dynamical and chemical evolution of galaxies. The one galaxy for which we can investigate *in detail* is our own Milky Way galaxy. While there have been wide ranging studies of Galactic star clusters, there remains a key problem with studying Galactic evolution: lack of large uniform samples. For photometric studies, this is starting to be possible with large-area

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surveys (e.g., 2MASS, SDSS-I, VVV, Skymapper, LSST). Large kinematic samples have begun to be derived utilizing proper motions (e.g., [12, 1, 4, 5, 7]) and radial velocities (e.g., [9]). However, high-resolution spectroscopy studies, yielding high accuracy radial velocities and detailed chemical abundances, are still limited to small sets of clusters¹. The soon to be commissioned Sloan Digital Sky Survey III/Apache Point Observatory Galactic Evolution Experiment (SDSS-III/APOGEE) will provide for uniform data and analysis for a survey of up to 200 star clusters.

2 SDSS-III/APOGEE

The SDSS-III/APOGEE project is three-year high-resolution spectroscopic survey that will cover all major Galactic populations (thin disk, thick disk, bulge/bar, and halo). The project utilizes a new 300-fiber-fed H -band (1.51 to 1.68 μm) spectrograph [23]. The spectrograph will yield $R = 27,500\text{--}31,000$ spectra with $S/N \sim 100$ per pixel for stars with $H = 12.3$. The goal of the survey is to derive precision radial velocities ($\sigma_v \leq 0.5 \text{ km s}^{-1}$) and abundances ($\sigma_{[X/Fe]} \leq 0.1 \text{ dex}$) for $\sim 100,000$ stars. The survey has planned to study 15 different elements (including Fe, C, N, O, α -elements, odd- Z elements, iron peak elements, possibly even neutron capture). The survey will coordinate observations with another SDSS-III survey, the Multi-object APO Radial Velocity Exoplanet Large-area Survey (SDSS-III/MARVELS) survey, which will necessitate that 75% of the observing time be spent in 58 key fields (which contain ~ 60 star clusters). The total APOGEE survey plans to target 220–230 unique field centers covering $\sim 1200 \text{ deg}^2$ of the sky.

2.1 APOGEE Calibration Clusters

One area of APOGEE science and calibration is the study of key star clusters listed in Table 1, with parameters taken from Harris catalog [14] for globular clusters and the Dias catalog [6] for the open clusters. These key clusters will have at least one 7 deg^2 plate configuration, up to 250 fibers, dedicated to likely cluster member stars. For some of the open clusters (e.g., M67, NGC 188, NGC 6819) we have kinematic membership and binary information available from the WIYN Open Cluster Study (WOCS; [19, 10, 15])

We will explicitly target many stars which have already been observed at high resolution ($R > 30,000$) in the optical or near infrared to be used to compare SDSS-III/APOGEE to other high-resolution studies. For these “calibration” cluster targets, we will obtain large numbers of members that will be used to fully characterize the clusters bulk chemical properties, but also allow science ranging for looking

¹ High-resolution studies of up to ten open clusters are starting to be published using CTIO/WIYN Hydra (e.g., [16, 8]) and VLT/Flames+UVES (e.g., [20, 2, 21])

for abundance variations on the individual element level to investigating isotopic abundance variations as keys to understanding evolution along the red giant branch.

Table 1 APOGEE candidate calibration clusters

Name		Type	Diam	[Fe/H]	$\sigma_{[Fe/H]}$	Age (Yr)	Log(Age)	Dist(pc)
NGC 188		Open Cl	17'	-0.01	0.09	4.2 Gyr	9.632	2047
Pleiades		Open Cl	110'	-0.03	0.06	135 Myr	8.131	150
Hyades	M45	Open Cl	330'	+0.13	0.06	787 Myr	8.896	45
NGC 2168	M35	Open Cl	25'	-0.16	0.09	95 Myr	7.979	816
NGC 2243		Open Cl	5'	-0.49	0.05	1.1 Gyr	9.032	4458
Melotte 71		Open Cl	7'	-0.30	0.06	235 Myr	8.371	3154
NGC 2420		Open Cl	5'	-0.40		2.8 Gyr	9.45	2290
NGC 2682	M67	Open Cl	25'	-0.15	0.05	2.5 Gyr	9.409	908
NGC 6171	M107	Globular	17'	-0.90	0.10	GC	GC	6400
NGC 6205	M13	Globular	25'	-1.51	0.10	GC	GC	7700
IC 4725	M25	Open Cl	29'	+0.17	0.06	92 Myr	7.965	620
NGC 6791		Open Cl	10'	+0.35	0.02	4.4 Gyr	9.643	5853
NGC 6819		Open Cl	5'	+0.07		3.1 Gyr	9.490	2360
NGC 6838	M71	Globular	9'	-0.79	0.10	GC	GC	6700
NGC 7078	M15	Globular	21'	-2.20	0.10	GC	GC	10300
NGC 7089	M2	Globular	21'	-1.62		GC	GC	11500
NGC 7789		Open Cl	25'	-0.20		1.7 Gyr	9.230	1820

3 APOGEE Candidate Cluster Analysis

3.1 Photometry Analysis

The only all-sky photometry that will be available for APOGEE targeting will come from two sources Two-Micron All-Sky Survey (2MASS JHK_S ; [22]) and the soon to be released *Wide-field Infrared Survey Explorer* (WISE; [24]) mission. However, since many of the targets will be in the Galactic midplane, and WISE has poor resolution (~ 6 arcsec), we will also supplement our data set with *Spitzer*/IRAC Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE I, II, 3D, 360; [3]) surveys, which provide better resolution in the needed [3.6] and [4.5] micron band-passes.

These surveys will provide five-band photometry $JHK_S[3.6][4.5]$ data which allow us to derive star-by-star extinctions utilizing the Rayleigh-Jeans Color Excess (RJCE) method (see Figure 1), fully described in Majewski et al. [17]. The RJCE method allows us to explicitly determine the A_{K_S} extinction to each star by using the observed $H-[4.5]$ color that is nearly constant for a large range of common spectral types. The ability to derive extinctions and correct to relative distance ranges is

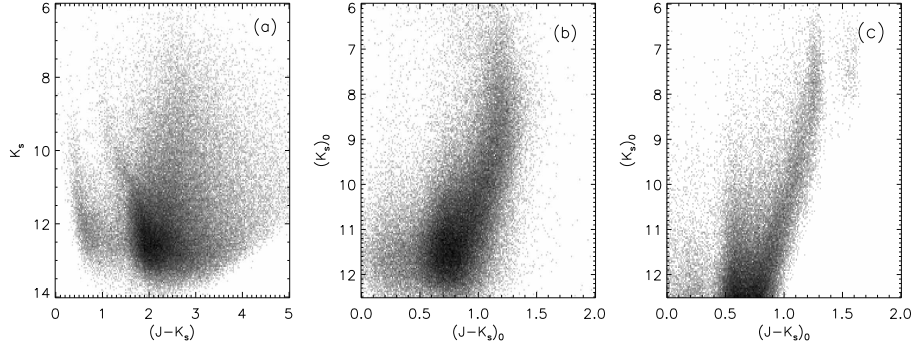


Fig. 1 Demonstration of the RJCE technique. a) Raw 2MASS CMD for a 4 deg^2 field at $(l, b) = (42, 0)$. b) Field dereddened using the RJCE technique. c) TRILEGAL [11] simulation of the Galaxy for a field at $(l, b) = (42, 0)$.

essential for a survey of the Galactic plane and bulge, and we can utilize this tool to isolate potential cluster stars from the field population.

3.2 Cluster Analysis

In order to distinguish and isolate star clusters from foreground and background contamination, we utilize the A_{K_s} values derived from the RJCE technique described above. We isolate a region of approximately twice the clusters catalog radius [6] and divide it into 5 regions (see Figure 2a). We utilize four “background” regions and the cluster region (radius = R_{Dias}). The background is divided in order to account for dust clouds, clusters near the edge of the GLIMPSE survey region, and any other source of background variability. We difference the mean field/background star numbers to the “cluster” star numbers within a given A_{K_s} range, and scan this range across all available A_{K_s} values that have at least 15 stars (Mean field + cluster stars ≥ 15 ; see Figure 2b). The window of extinction with the highest concentration of stars within the inner radius will reveal the cluster (Figure 2c & d). We then work to optimize the cluster isolation surveying a grid of A_{K_s} width, A_{K_s} stepsize, and allowed $\sigma_{A_{K_s}}$ values.

3.3 Preliminary Results

We present a first analysis for the cluster NGC 6802 to demonstrate the technique, shown in Figure 2. Figure 2a first shows the area explored by our analysis in Galactic latitude and longitude. As described above, we selected likely cluster members utilizing the A_{K_s} as shown in Figure 2b. For NGC 6802 we find a low, but non-negligible

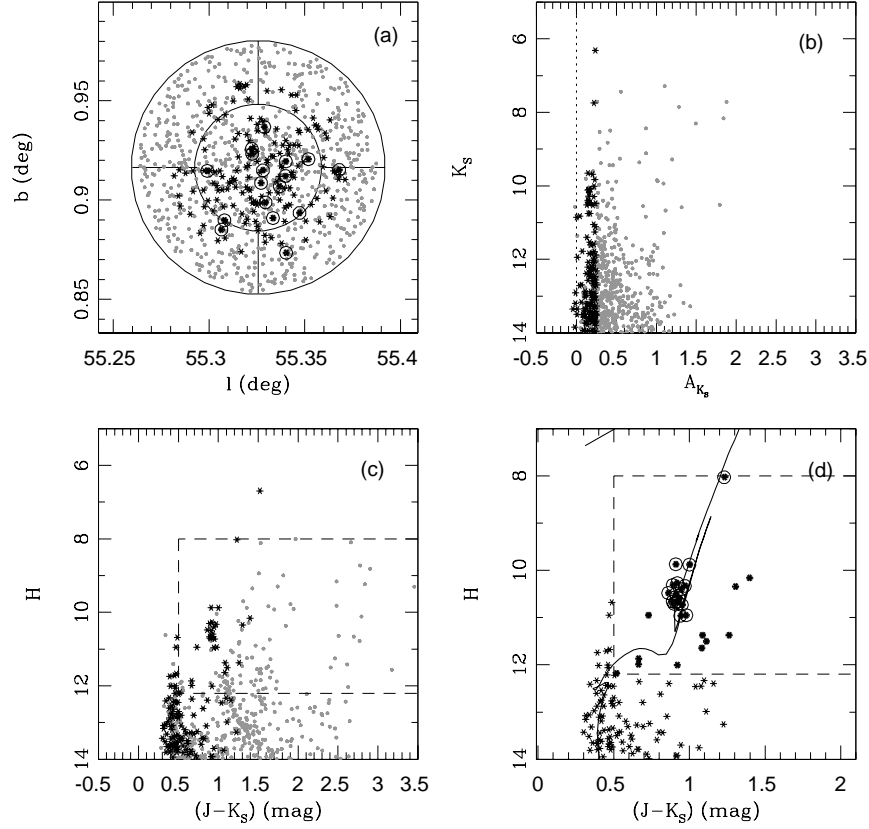


Fig. 2 Sample analysis for the cluster NGC 6802 utilizing 2MASS+GLIMPSE data. a) Galactic latitude and longitude for all stars (gray) within the $2R_{cl}$ area to be analyzed, stars selected to be likely members from the photometry extinction analysis are shown in black. Prime APOGEE targets are circled. b) Distribution of A_{K_s} for all stars in the NGC 6802 sample area, black points denote stars with $1.1R_{cl}$ within the determined mean cluster A_{K_s} range. c) Color-magnitude diagram (CMD) for all stars in the analysis area (gray). The dashed box denotes the SDSS-III/APOGEE target selection region. Black points denote stars selected as likely members from their A_{K_s} . d) CMD of only likely cluster members overplotted with the Padova Isochrone [18] using the clusters parameters from [6]. Circled stars denote identified high-probability stars for APOGEE target selection (also see the on-sky distribution in (a))

extinction or reddening to the cluster. A color magnitude diagram (CMD) of the clusters (Figure 2c) is generated which highlights the member stars with A_{K_s} values within the window of extinction, where the dashed box in the center denotes the area where the upcoming SDSS-III/APOGEE project will be targeting ($8.0 < H < 12.3$ and $J - K_s \geq 0.5$). Finally, we compare our “cleaned” cluster CMD to the Padova isochrone utilizing catalog values [6] for NGC 6802 and find a good match. By com-

paring the CMD with isochrone values, when available, we are able to isolate candidate cluster stars with a high probability for membership. The APOGEE project requires this cleaning for most clusters for two reasons: 1) most open clusters are found at a low Galactic latitude and thereby are heavily contaminated with field stars. 2) Due to the large SDSS telescope field of view [13], the minimum fiber-to-fiber distance is fairly large ≥ 1 arcmin, which only allows for the targeting of a handful of stars ($\sim 5 - 10$) per cluster for the most poorly studied, distant, and reddened clusters.

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